Technical Paper 19

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE FACTOR OF SAFETY
IN
MINE ELECTRICAL INSTALLATIONS

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

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THE FACTOR OF SAFETY IN MINE ELECTRICAL INSTALLATIONS.

By H. H. Clark.

INTRODUCTION.

This paper is not written for the purpose of discouraging the use of electricity in mines. The advantages that have in the past attended the use of electricity in mining work will be even more apparent in the future as operations are extended, power systems consolidated, and generating stations centralized. A discussion of these advantages is unnecessary since they are well known to everyone interested in the subject. The purpose of this paper is to urge that the requirements of safety, as well as those of efficiency, be considered in the installation and operation of electrical mining equipment. The Bureau of Mines publishes this report as one of a series dealing with the use of electricity and the prevention of electrical accidents in mines.

A factor of safety may be regarded as representing the ratio of maximum capacity to average duty. Factors of safety are used in the solution of engineering problems in which the conditions can not be exactly determined in advance, or in which unforeseen happenings may arise to introduce severe stresses. Especially does this apply to problems in which the safeguarding of human life is a consideration.

The use of a factor of safety is not a sign of poor engineering, but quite the contrary. Good engineering is based upon recognizing conditions, not upon ignoring them. The wise engineer prepares for emergencies instead of assuming that the emergencies will not arise. A factor of safety is good insurance, which is everywhere recognized as a business necessity.

The safe operation of electrical mining equipment is an engineering problem that involves the element of human life and that is influenced by conditions and events that can not always be foreseen. The successful solution of the problem will, therefore, depend largely upon the factor of safety that is considered in the selection, installation, and maintenance of such equipment.

In problems in which the factor of safety can be expressed numerically it is seldom made less than three, and often more than 30. In

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the present discussion the factor of safety can not be numerically expressed because neither the capacity for safety nor the duty to be performed in preventing accidents can be measured in the same terms, or even in any terms at all. Therefore, more care, better judgment, and more liberal allowances in design, construction, and installation are required to insure a factor of safety than would be required if its existence were susceptible of mathematical proof. But above all, the absence of a mathematical basis for argument demands great courage of conviction on the part of those advocating increased expenditures in the interest of safety.

To facilitate consideration, the problem may be divided into two principal parts: First, an analysis of the conditions to be met; second, a discussion of how to meet them and insure a desirable factor of safety.

CLASSIFICATION OF ACCIDENTS DUE TO ELECTRICITY.

In analyzing the relation that the use of electricity in mines bears to the accidents that occur there, the first step is to classify the different ways in which electricity can cause injury, death, or disaster.

One characteristic of the electric current with which everybody is familiar is its ability to produce electric shocks. The conditions underground are favorable to their occurrence. There is a well-known fire risk in connection with the use of electrical apparatus. The use of electricity in the vicinity of gas, explosive dust, or explosives, all of which may be found in mines, is attended with danger. There are, therefore, in connection with the use of electricity in mining work three possible dangers—shocks, fires, and explosions.

ELECTRIC SHOCKS.

The conditions under which electricity can start a fire or cause an explosion may be absent from a mine at any or all times, but the chance of receiving an electric shock is always present in any mine where electricity is used and men are at work.

Many conditions that are peculiarly favorable to the occurrence of electric shocks are found in mines. Most of these, such as dampness, dust, limited space, and scanty light, are unavoidably associated with mining work. In addition, many underground employees are unfamiliar with electrical apparatus and the proper way to regard it. They may have no responsibility as to its operation or condition, nor any direct interest in it whatever. To some of them electricity may be not even a name or at most only something about which conflicting and confusing statements are made. Yet though the conditions underground favor electric shocks and though the men may be unfamiliar with electricity, trolley wires and uninsulated feeders are frequently found operating at 250 and 550 volts, the earth being used almost universally as the common return for all direct-current apparatus.

DANGER FROM GROUND-RETURN CIRCUITS.

Under the best of conditions ground-return circuits offer more chances for shock than do completely insulated circuits. The risk is increased where workmen are obliged to stand upon the ground when handling apparatus operating with ground returns. In ground-return systems one side of the generator is connected to the earth, to the track-rail network, and to the return feeders which are in parallel with both. As a result anyone who stands upon the ground stands upon one side of the electric circuit and only a single contact with the other side of the circuit is necessary to give a shock.

DANGERS FROM TROLLEY WIRES OR BARE CONDUCTORS.

Trolley wires in mines present a most fruitful source of electric shock. Trolley wires are necessarily bare conductors; they may extend for long distances throughout a mine, and often they must be installed less than a man's height above the track rail which is used as part of the return circuit. A low trolley wire is especially dangerous in places where men must work in making up trips of cars, as at partings where loaded trips are brought out to the foot of a rope-haulage system. Under such circumstances both the loaded and the empty trips are in the parting at the same time, and manipulation is required to make up the loaded trip to be taken out on the rope and to split up the empty trip to be taken in by the various locomotives. It is often desirable to do this work rapidly, and if the trolley wires are lower than a man's head the chance for shock is considerable. Even if the men are familiar with the conditions their attention, while hurrying to get the trips away from the parting, can not be constantly on the trolley wire.

Trolley-wire feeders and the wires of circuits that operate motors of any description, if exposed to the same extent, offer the same chance of shock as does the trolley wire. Usually such exposure is not necessary, however, as the wires can be strung along the sides of entries in positions less accessible to persons passing. It is also possible to insulate or protect the wires.

DANGER FROM ACCIDENTAL CHARGING OF EQUIPMENT.

Apparatus that has accidentally come in contact with the ungrounded side of an electric circuit is almost as dangerous as the trolley wire. If such apparatus is metallic and is insulated from the earth it offers all the necessary conditions for giving a severe shock, and the danger from such a shock is accentuated by the fact that the victim, being unaware of his proximity to danger, may firmly grasp the charged part. If a shock is received while the victim is grasping the source of current, the results are more likely to be severe than under other conditions, because the grasp is " frozen " in place by the sudden contraction of the muscles, and voluntary release from contact with the circuit is impossible. By connecting to the earth such parts of apparatus as are made of conducting material but are not designed to carry current they can not become charged with electricity to a potential above that of the earth; consequently a shock can not be obtained by a person's establishing contact between such parts and the ground.

SHOCKS FROM LOCOMOTIVES AND CARS.

There are certain ways in which shocks can be received from locomotives and mine cars. The frames of locomotives are connected to the current-carrying parts of the motors and become charged whenever the motors or headlights are in operation. If the locomotive loses its ground or contact with the rail by reason of oversanding or for any other cause, the full line potential exists between the frame of the locomotive and the rail. Under such circumstances as severe a shock can be obtained from the locomotive frame as from the trolley wire.

Since the drawbars of the mine cars are connected to the locomotive frame and are continuous throughout the length of the trip, it follows that, whenever the locomotive loses its contact with the rail, all the drawbars are raised to the potential of the trolley wire unless some of them are in contact with the car axles, axle boxes, or some of their connections.

RELATIVE DANGER FROM DIFFERENT VOLTAGES.

An electric shock is caused by the passage of current through the human body, the severity of the shock depending upon the amount of current passed. The amount of current depends upon the voltage and the resistance of the circuit, the latter including the resistance of the body, the resistance of its contact with the source of current, and any resistance that may be in series with the body, such as ground resistance. Obviously, therefore, all other factors being equal, the severity of the shock varies with the voltage causing it. There are voltages so small that they are not capable of passing through the body current sufficient to produce a shock. As these voltages are exceeded, a value is reached at which shocks begin to be felt. As the voltage is further increased a value is reached such that shocks may be fatal if the contact is maintained for a sufficiently long time. At still higher voltages the period of contact necessary to cause death becomes shorter.

The effect of any shock depends so much upon the particular conditions involved that no specific values of voltage can be assigned to any of the conditions mentioned. The physical makeup of a man greatly affects the outcome. Some men seem practically immune from shocks from potentials as high as 500 volts, while others may be killed by a much lower voltage.

As regards the relative danger of a current having a potential of 250 volts and one having a potential of 500 volts, both have been known to cause fatal shocks. Compared with a 250-volt potential, a 550-volt potential not only passes more current through a man's body under a given set of conditions, but it is also more likely to break through insulation to ground. The higher voltage will pass the same current through poorer contacts and greater resistances than will the lower.

FIRES CAUSED BY ELECTRICITY.

The danger from fires caused by electricity arises principally from defective installation, careless upkeep, or from injuries to equipment resulting from falls of roof or similar causes. A short circuit or a ground that does not blow the circuit breaker nor the fuses may produce heat enough to start a fire by leaking across coal or timbering. The blowing of an open fuse is accompanied by sufficient heat to ignite combustible material that is very close to the fuse, especially if for any reason the arc is long drawn out. The presence of inflammable material around electric motors or starting boxes may prove to be a source of trouble. Incandescent lamps produce heat enough to ignite combustible materials if the dissipation of heat from the bulbs of the lamps is allowed to become restricted. With conductors bare and with both sides of the circuit strung side by side there is a chance that leakage from one side to the other across coal or damp timbering may produce heat enough to start a fire.

The conductivity of coal, especially dry coal, is usually very low. This fact tempts careless workmen to poor construction and poor installation; also it aids in covering up these defects. Such poor work might be logically expected were it not for the fact that, under some conditions, grounds to coal will produce sparking, arcing, and heating enough to start fires.

Inflammable material should never be allowed to collect about a motor or in the vicinity of fuses or other apparatus that can produce arcs, flashes, or considerable heat.

To provide a factor of safety, starting boxes, fuses, and all apparatus that may throw off sparks under normal conditions, or that are subject to abnormal conditions that result in the production of even greater heat, should be mounted on or protected by a sheet of metal or other strong noncombustible material.

EXPLOSIONS CAUSED BY ELECTRICITY.

Explosions may be caused by the ignition of explosives, gas, or coal dust.

IGNITION OF EXPLOSIVES.

Accidents due to the ignition of explosives by electricity may be divided into two classes: Those that occur while handling and transporting explosives near electric circuits and those that are incident to the detonation of explosives by electrical means.

As to accidents of the first class (with a single exception noted below), electricity is no more of a menace than any other source of flame and heat, but it is as great a menace and should be treated accordingly. As much care should be used in handling explosives in the vicinity of electrical apparatus as though the flashes and sparks that it is capable of giving were constantly in evidence.

Any source of heat may attack an explosive from the outside, but electricity may, under certain conditions, do more than that. An explosive that is a conductor of electricity may come in contact with an electric circuit in such a way that current may be passed through the explosive itself, and although no spark may occur outside the package, ignition may take place on the inside. The possibility of such an occurrence may seem to be extremely remote, but accidents have been reported for which no other cause could be assigned and in which the existence of the above conditions was quite probable. As mentioned in a foregoing paragraph, it is possible, when mine cars of a certain type are used, that a considerable difference of potential may exist between the drawbars and those metallic parts of the car that are in electrical connection with the track rail. If such a car were loaded with metallic packages of explosives, the points of different potential might be so joined that current would flow through the packages and possibly through the explosive itself.

ACCIDENTS DUE TO ELECTRICAL SHOT FIRING.

The accidents that occur in connection with electrical shot firing are due, for the most part, to the accidental discharge of detonators in the vicinity of explosives or to the premature ignition of shots after holes are charged. With regard to the accidental discharge of detonators in the vicinity of explosives, a cardinal principle of safety is that detonators should be kept separate from explosives and that batteries and other sources of electric energy should be kept separate from detonators.

With regard to the premature ignition of shots, it is not the best practice to shoot electrically under conditions that require one side of the detonating circuit to be connected to the earth, because whenever grounded systems of distribution are used unexpected differences of potential exist in the earth in the vicinity of such circuits. If, therefore, one side of the detonator be purposely grounded, an accidental ground on the other side may connect the detonator across a potential sufficient to cause ignition. Premature ignitions have been reported which seemingly have been caused by the conditions just described.

IGNITION OF GAS.

Electric sparks will ignite mine gas and air mixtures that contain between 5 and 11 per cent of gas (methane). Between these limits a comparatively small spark is sufficient to fire the gaseous mixture. The size of arc or spark that will occur when an electric circuit is opened depends upon a number of things, such as the voltage of the circuit, the amount of current broken, the speed of break, and the character of the circuit. The determination of the exact influence of each of these factors is an interesting problem. For all practicable purposes, however, it is safest to assume that all sparks which occur around such apparatus and circuits as are used for power and light in a mine are capable of igniting gas. Although this assumption may not be correct at all times, the continually varying conditions surrounding such equipment make a contrary assumption unsafe. For instance, a motor that is so well designed and so adapted to its load that the commutating sparks are too minute to ignite gas may, in starting, develop dangerous sparks.

The ignition of gas by electric incandescent lamps is now being investigated by the Bureau of Mines. A large number of lamps of various sizes are being broken in different ways while surrounded by a highly explosive mixture of gas and air. The results so far obtained show that certain sizes of lamps when broken in the presence of gas will ignite it, and that in the action of the lamps there is a difference which depends upon the size of the filament, the larger filaments being more likely to ignite gas than the smaller ones.

IGNITION OF COAL DUST.

The study of the ignition of coal dust by electric arcs and electric flashes has been undertaken to some extent by investigators in Europe. The results of their experiments indicate that electric flashes can ignite coal dust suspended in the atmosphere. The Bureau of Mines is now devising apparatus preparatory to making an extensive investigation of this subject.

CONDITIONS SURROUNDING ELECTRICAL INSTALLATIONS IN MINES.

The conditions surrounding electrical apparatus in mines are more severe and less constant than those surrounding similar installations above ground; there are more trouble-causing factors than are found upon the surface.

PHYSICAL CONDITIONS.

Falls of roof sufficient to wreck trolley lines and feeder systems are not uncommon. Dampness, dust, and acid water in sufficient quantities to be detrimental to insulation are present in many mines. Some or all of these conditions must usually be considered in selecting mine electrical equipment. Apparatus that might operate satisfactorily in the absence of these elements will fail when they are present.

The space available for installing and operating underground electrical equipment is usually limited, thus increasing the chance for accidental contact with the live part of the system.

Another factor that has more influence than is usually recognized is the lack of light. Not only has this condition a direct bearing upon accidental contact with electrical apparatus, but it also has an undesirable indirect influence because of the difficulties which it places in the way of properly installing and inspecting the equipment.

TEMPORARY CHARACTER OF INSTALLATIONS.

As compared with electrical installations on the surface those underground are temporary in character. Circuits and machines are put in place with the certain knowledge that sooner or later they must be removed and installed elsewhere. This fact undoubtedly has an undesirable influence upon the quality of work performed. For economic reasons it is not practicable to resort to methods of installation that would be followed if the work were to be permanent. The men who direct the work must have peculiarly good judgment and must be keenly alive to all the requirements of the situation if a suitable factor of safety and a desirable low installation cost are to be maintained. Although elaborate methods of installation may in time pay for themselves in low cost of maintenance, such methods are not economical if the equipment is to be moved frequently. Obviously, an installation investment in excess of the amount necessary for satisfactory operation during the period of service is an entire loss. If the period of service is to be short, there is a natural tendency to limit the cost of installation. Whether such curtailment is wise depends so largely upon circumstances that no general statement can be made. However, undue reduction in installation expenditures not only reduces the factor of safety at one point but also lowers the general standard of workmanship throughout the mine. If no accident occurs as the result of poor or cheap work, it is natural to assume that the work met the requirements. The fallacy of making a general application of results obtained in a single instance is manifest at a glance. Yet arguments of this kind have undoubtedly been used in the past to justify inferior work.

THE PREVENTION OF ACCIDENTS CAUSED BY ELECTRICITY.

The problem of safeguarding electrical mine equipment is not a simple one. There is no general formula or equation for its solution. Moreover there are so many variables involved, so many factors that can not be exactly related, so many possible coincidences, that results can not be predicted with mathematical exactness. It is necessary to consider each part of the problem by itself, in the light of local conditions, and to adopt such measures as insure a large factor of safety.

ELIMINATION OF CONTRIBUTORY CAUSES.

A logical first step would be to remove or to counteract as many unfavorable conditions as may be disposed of thus.

As previously stated, scanty light, limited space, and the presence of dust and dampness are underground conditions that are favorable to the occurrence of electrical accidents. The influence of the first of these may be eliminated by providing lights at particularly dangerous places, such as partings and crossovers. If electric wires are a source of danger at such places they can be made a source of light also.

Although it may be impracticable to eliminate entirely the effect of limited space, this condition may be counteracted by the erection of guards about apparatus.

Dust and dampness are elements that can hardly be separated from the operation of a mine; in fact, the presence of dampness is often desirable to offset the effect of dust. It is possible, however, to provide apparatus so designed and installed as to resist the action of dust and dampness, and the more generous the factor of safety included in such design and installation the greater will be the resistance.

CONFINEMENT OF THE CURRENT.

The problem of safeguarding may be divested of some of its vagueness and put in concrete form by considering that if the electric current can be kept where it belongs—in the conductors designed to carry it—it can not give shocks, set fires, or ignite gas, dust, or explosives. Electricity becomes actively dangerous only when it breaks away from its proper channels in stray currents or as sparks and arcs.

As far as stray currents are concerned the confinement of electricity in its proper place is primarily a question of insulation, a term that includes the covering of conductors, the insulators upon which they are supported, and the insulating material used in motors and accessory equipment. Against insulating coverings for con-

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ductors is brought the argument that such coverings deteriorate rapidly and are an added element of danger because they give false impressions of safety. The truth of this argument depends upon the kind of insulation and the conditions of service, and can not be regarded as universally applicable. If bare conductors are used they must be well installed and, to some extent at least, guarded, in order to confine the current. With the possible exception of high-voltage cables all conductors, bare or insulated, should be supported upon insulators that are mechanically strong as well as electrically efficient. If bare conductors are used, confinement of the current depends entirely upon the insulators. Moreover, dampness and dust can come into direct contact with the wire, a condition not consistent with the highest factor of safety.

In order to insure a high factor of safety in the insulation of motors and other electrical machines they must be carefully selected with a view to the service which they are to perform. They must then be protected from moisture and dust unless such protection is inherent in their design. Care in this respect will be rewarded not only by increased safety, but also by decreased cost of upkeep. The maintenance cost of inclosed motors operated in damp and dusty places should be less than for open motors operated under the same conditions if both types of machines are properly designed, constructed, and rated.

It must be admitted that the electric current can not be kept where it belongs in the sense of eliminating entirely such sparks and arcs as occur at fuses, circuit breakers, air-break switches, starting rheostats, and the commutators of direct-current machines. In this connection the factor of safety must be applied by arranging to confine the outbursts of current to a limited area unoccupied by anything which may be affected by heat or fire.

ADDITIONAL PRECAUTIONS.

Assuming that in the selection and installation of electric equipment care has been exercised to insure the proper confinement of the current, the factor of safety may be increased by grounding the dead metallic parts of apparatus, by providing means for insulating the bodies of those who work upon such apparatus, and by barring from the vicinity of the current such elements as are explosive or combustible.

MAINTENANCE OF SAFETY FACTOR.

It is as important to maintain a high factor of safety as to obtain it in the first place, and this requisite calls for careful and frequent inspection by the mine electrician, whose responsibilities can scarcely be overrated. The supervision of the electrical equipment of a mine is a task that requires unusual ability, sound judgment, and experience of a peculiar sort. To select suitable apparatus, to install it properly and economically, and to maintain it free from interruption of service at a minimum cost demands much ability. When the requirements of safety are added to the list of duties the responsibility is not lessened. The establishment and maintenance of a high factor of safety rests as much with the man who has direct charge of the electrical equipment as with anyone. It seems reasonable also to assume that a man who is competent to maintain a high factor of safety is no less able to maintain as low a cost of maintenance as is consistent with satisfactory operation.

SUMMARY.

By way of a summary there follow five terse suggestions for reducing the number of accidents due to the use of electricity in mines:

1. Remove contributory causes.

2. Remove from the vicinity of electrical apparatus all elements susceptible to its influence (gas, dust, explosives, combustible material, etc.).

3. Keep the electric current where it belongs.

4. If under certain circumstances the current can not be entirely confined, at least limit the area of its activity by using protective devices.

5. Insure a high factor of safety by: (*a*) Selecting materials and apparatus with care; (*b*) installing equipment in a strictly first-class manner; (*c*) inspecting equipment frequently and thoroughly; (*d*) maintaining it in good condition at all times.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 26. Notes on explosive mine gases and dusts, by R. T. Chamberlin. 67 pp. Reprint of United States Geological Survey Bulletin 383.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

Technical Paper 6. The rate of burning of fuse as influenced by temperature and pressure; by W. O. Snelling and W. C. Cope. 1911. 28 pp.

Technical Paper 7. Investigation of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1911. 19 pp.

Technical Paper 11. The use of mice and birds for detecting carbon monoxide after mine explosions and fires, by G. A. Burrell. 1912. 16 pp.

Technical Paper 12. The behavior of nitroglycerin when heated, by W. O. Spelling and C. G. Storm. 1912. 14 pp.

Miners' Circular 2. Permissible explosives tested prior to January 1, 1911, and precautions to be taken in their use, by Clarence Hall. 1911. 12 pp.

Miners' Circular 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

Miners' Circular 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

Miners' Circular 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.